MODELING CALIFORNIA SALMON FLEET DYNAMICS[1]

David Tomberlin
National Marine Fisheries Service

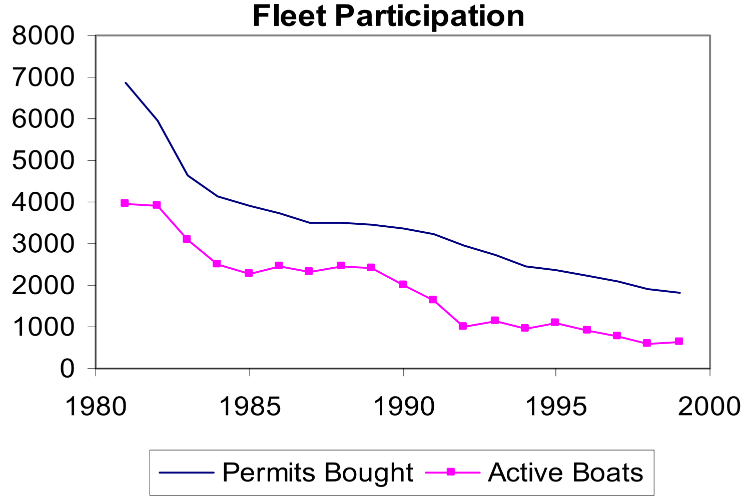
Abstract

This paper describes ongoing research into the dynamics of the California commercial salmon fishery. The fishery is limited-entry in that the salmon vessel permit must be renewed each year: if allowed to lapse, the permit cannot be reactivated. This element of irreversibility in the exit decision suggests that real options may be an appropriate modeling framework to describe and predict fleet dynamics in this fishery. Two real options models are developed and tested against each other and against a competing hypothesis of exit decisions based on a net present value criterion. The real options models have significantly more explanatory power than the present value model, and taken together suggest that fleet dynamics are more driven by average boat performance than by total fleet performance. The final section describes work in progress to develop more complete formulations of the model.

Introduction

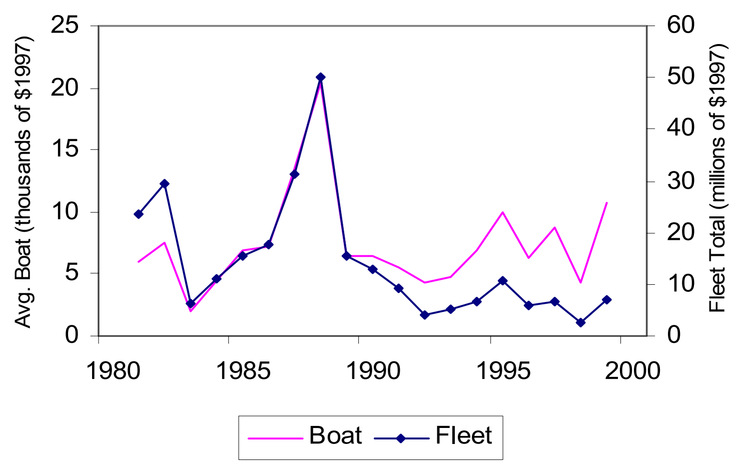
In the past two decades, the number of commercial fishing vessels landing salmon in California has declined steadily (Fig. 1). Season and catch restrictions, decreasing fish stocks, and falling prices have all contributed to discouraging participation in this fishery. Real fleet revenues have trended downward, though there was a strong spike during 1987-88, while real revenues for the average boat remaining in the fishery have actually trended slightly upward (Fig. 2). Commercial fishing effort is an important management consideration, particularly because many boats not actively fishing maintain the right to re-enter the fishery through the purchase of annual salmon vessel permits. An understanding of the conditions under which boats exit the fishery is therefore of some practical interest.

Fig. 1: California Commercial Salmon Fleet Participation



[1] Many thanks to Dave Colpo of the Pacific States Marine Fisheries Commission for providing data and more data.

Fig. 2: Real CA Commercial Salmon Revenues--Avg. Boat and Total Fleet



This paper explores the suitability of a real options approach to modeling exit behavior in a limited-entry fishery[2]. This approach is motivated by two key aspects of the decision facing fishermen: the uncertainty of fishing revenues and the irreversibility of the decision to leave the fleet. Wide fluctuations in annual boat and fleet revenue from salmon, due to both catch and price variability, introduce significant uncertainty. Irreversibility of the exit decision arises because the California ocean salmon fishery is a limited-entry fishery: once a salmon vessel permit has been surrendered, the right to fish for salmon is lost irrevocably. Fishermen have the option to exit the fishery (by giving up their salmon vessel permit) but can postpone the exercise of that option, allowing them to reassess the situation continually. The value of the exit option depends on the value of the underlying asset, fishing revenues. If revenues are very high, the option to exit has little value. If revenues are low—perhaps even lower than costs—the option is more valuable, but the potential for better times ahead may persuade fishermen to stay in the fishery while they wait for more information, since once they exercise the exit option they cannot get back into the fishery.

For many fishermen, of course, the decision to leave a fishery permanently will depend on a variety of factors not reflected in the simple model described below—personal and social considerations as well as other economic considerations (e.g., credit constraints). The goal of this paper is not to provide a complete explanation of exit behavior in this fishery, but to assess the explanatory power of the real options approach. The next section presents a simplified model of the decision to exit the salmon fishery. For the purposes of this paper, the fisherman's problem is represented as a simple choice between prosecuting the fishery or exiting irrevocably, where 'exit' means ceasing to land salmon commercially. The specific role of the renewable salmon vessel permit is the subject of another manuscript under development.

[2] The real options literature has developed in the last two decades as an outgrowth of the financial options valuation literature. Dixit and Pindyck (1994) provide an overall guide to the field, and Conrad (1999, Ch. 7) provides a textbook presentation of some natural resource applications.

A Model of the Exit Decision

A fisherman active in the California salmon fishery has several options: to continue fishing for salmon; to suspend salmon fishing but maintain the right to fish later by purchasing a salmon vessel permit each year; to exit the salmon fishery for good, perhaps prosecuting some other fishery; or to sell his boat, exiting all fisheries. Below, the decision problem is reduced to a simpler form: the fisherman faces a choice between staying in the salmon fishery or exiting, i.e., ceasing to land salmon, thereby giving up the right to resume fishing later. Details of addressing this type of problem are given in Dixit and Pindyck (1994)—the following sketch of the steps follows their notation as closely as possible.

While the fisherman continues to land salmon, he receives the periodic revenue R (no cost data is currently available in this fishery). Because future revenues are unknown, R is a random variable. A not unreasonable representation of the stochastic process governing the evolution of R is Geometric Brownian Motion (GBM), which implies that percent changes in R from year to year are normally distributed. The GBM process is formulated as

$$dR = \alpha R dt + \sigma R dz \qquad (1)$$

where α is the instantaneous rate of change of R, σ is a volatility parameter, and dz is a standard Brownian motion. The process thus described is the continuous-time analogue to a random walk with drift.

If the fisherman exits the fishery, he exchanges the expected capitalized value of the revenue stream for a salvage value S. S may be the value of other available fisheries, or of selling the boat. Traditional capital budgeting (present value analysis) involves comparing the salvage value S to the capitalized value of expected future earnings (call it V) and taking the larger of the two. However, if V is stochastic, even if the fisherman is losing money, the prospect that revenues, and thus V, will rebound in the future may be sufficient to keep him in the fishery.

The problem facing the fisherman can be formulated as an optimal stopping problem in dynamic programming, the Bellman's equation for which is

$$F = \max\{S, R + (1+\rho dt)^{-1} E[F(R+dR, t+dt) | R]\} \qquad (2)$$

That is, the fisherman faces a trade-off between the salvage value S and the value of continuing in the fishery, which is itself the sum of periodic revenue R and the discounted value of expected future revenues. We seek the trigger value of R (call it R^*), the value at which the fisherman is indifferent between exiting and staying in the fishery (while maintaining the option to exit). For $R > R^*$, the fisherman will prefer to stay in the fishery, while for $R < R^*$ he will prefer to exit for good. In the continuation range (i.e., $R > R^*$), we can apply Ito's lemma to (2) to derive a stochastic differential equation which F must satisfy:

$$\frac{1}{2}\sigma^2 R^2 F''(R) + \alpha R F'(R) - \rho F(R) + R = 0 \qquad (3)$$

The solution to this SDE, which gives the expected value of an active fishing boat with the option to exit, is

$$F = AR^{\beta} + \frac{R}{(\rho - \alpha)} \tag{4}$$

where A is an unknown constant and β is the negative root of the fundamental quadratic of (3). Two technical conditions are invoked to derive the trigger value R^* from (4). The value-matching condition requires that, at R^*, the value of the project given up must equal the value of whatever is received in exchange, here the salvage value S. Thus,

$$F(R^*) = S \tag{5}$$

The second condition, the smooth-pasting condition, requires that rates of change in the value of the project and the salvage value be tangential at R^*:

$$F'(R^*) = S' \tag{6}$$

These conditions are sufficient to solve for R^*, which in this case is

$$R^* = S(\rho - \alpha)\frac{\beta}{\beta - 1} \tag{7}$$

This R^* is the value at which the model implies a representative boat will exit the fishery; it provides a basis for an empirical test of the model, described next.

Empirical Application

The model suggests that boats experiencing $R > R^*$ in a given period will remain active in the fishery, while those experiencing $R < R^*$ will exit. Thus, for each boat, in each period (here, each year) during which the boat is active, comparing observed R to R^* provides a prediction of whether the boat should remain active or exit in that year. This predicted behavior can then be compared to observed behavior to assess the model's explanatory power.

The universe of boats considered includes any boat that landed salmon in California at any time during 1981-99. Annual data on California salmon landings and revenues from 1981 to 1999 are from the Pacific Coast Fisheries Information Service (PacFIN), maintained by the Pacific States Marine Fisheries Commission. Maximum likelihood estimation of two revenue series, fleet total and average boat revenues, produced the estimates of the drift parameter α and volatility parameter σ given in Table 1.

Salvage value was calculated as simply the average boat's total revenue (from all species and ports on the West Coast) less its revenue from salmon landed in California. Salmon landed in other states are thus attributed to salvage value, or what fishermen would get if they left the California salmon fishery. (The main sources of other revenues for the fleet are dungeness crab and albacore.) An attempt to calculate salvage value as the average revenues of boat that have similar tonnage and horsepower characteristics to salmon boats yielded salvage values much higher than average salmon revenues, and so was rejected as an inappropriate representation of other opportunities available to salmon boats. Further work on the salvage value of vessels in this fleet is needed.

Three competing hypotheses of exit behavior are examined, in each case assuming a discount rate of 5%. The first hypothesis, "NPV", derived from the net present value model, is that the fisherman chooses the larger of the salvage value (obtained by exiting) or the expected capitalized value of staying in the fishery. The second hypothesis, "TOT REV", is that the fisherman solves the optimal stopping problem (2), where the parameters governing the evolution of R are those for total fleet revenue. This model suggests that fishermen expect to have a fixed share of total fleet revenue, so that their own fortunes mirror those of the fleet. The third hypothesis, "AVG REV" is that the fisherman solves equation (2), where R is governed by the parameters of the average boat revenue process. This hypothesis implies that fishermen care not about the overall fortunes of the fleet, but about the performance of the average active boat.

Each of these hypotheses generates a prediction, for each year for each boat, of whether the boat should exit in that year or not, based on whether the revenue it receives exceeds the threshold value R^*. Because the different behavioral hypotheses generate different trigger values R^*, we can compare the predictive powers of the different models. The data set used for the tests contains 35,466 boat-year observations, for each of which the models' predictions are tested against observed behavior.

Table 2 presents comparative results of the tests for the three hypotheses. Each cell in the upper part of the table shows the number of boat-years for which observed behavior matched or conflicted with the predictions of the three hypotheses. For example, of the boats predicted by the hypothesis "NPV" to exit, 5238 did exit and 22,850 did not. Thus, 19% of this model's exit predictions were correct. By contrast, 95% of its "stay" (i.e., stay active) predictions were correct. Dividing the sum of correct exit and correct stay predictions by the total number of predictions made yields the rate of overall correct prediction, here 35%.

Table 2: Predictive Performance of the Competing Hypotheses

Observed Behavior	***Predictions, by Hypothesis*** "NPV"		"TOT REV" (α = -.07, σ = .69)		"AVG REV" (α = .03, σ = .61)	
	Exit	Stay	Exit	Stay	Exit	Stay
Exit	5238	335	4461	1112	3128	2445
Stay	22,850	7043	14,762	15,131	7130	22,763
Total	28,808	7378	19,223	16,243	10,258	25,208
	Percent of Corroborated Predictions					
Marginal	19%	95%	23%	93%	30%	90%
Total		35%		55%		73%

The traditional capital budgeting hypothesis, "NPV", performs very poorly in predicting exit, and very well in predicting the decision to stay active. This is because it sets $R^* = S$, which is much higher than the R^* generated by the real options models. The "TOT REV" hypothesis, that fisherman base their decisions on the stochastic process governing total fleet revenues, predicts far fewer exits than does "NPV," and thus predicts exit accurately more often but "stay" less often (in percentage terms) than does "NPV." However, "TOT REV" manages a significantly higher overall predictive accuracy than does "NPV" by predicting a much higher number of "stay" decisions. The "AVG REV" hypothesis, that fishermen base their decisions on the stochastic process governing the average active boat's revenues, does better still: of the 35,466 predictions, 73% are correct.

Conclusions

The real options approach to modeling California salmon fleet dynamics seems to have more power to explain past trends in exit from the fishery than does a competing present value model. Further, the tests conducted here suggest that the expected fate of the average boat is a better gauge of fishermen's participation criteria than is total fleet performance.

The chief advantages of the real options approach are explicit recognition of irreversibility and the option to delay decisionmaking. Some potentially significant pitfalls of the method are that it admits few state and decision variables, is developed in continuous time (though it need not be), and requires the specification of an exogenous discount rate. It also makes strong assumptions about fishermen's access to information and use of that information.

While these preliminary results suggest that this framework may have some utility for the analysis of limited-entry fisheries, a number of questions remain, and extensions to the basic model are being developed. The first is an explicit representation of the salmon vessel permit, which enables fishermen to suspend fishing while maintaining the right to re-enter the fishery later. Separate representations of the fish stock and price processes would tie the fleet dynamics model more directly to policies that affect these processes independently, such as area closures or international trade policies. Addressing boat and fisherman heterogeneity (say with respect to skill, risk tolerance, or motivation) is another direction for further work. The inclusion of cost data and a more appropriate formulation of salvage value would enhance the model's realism (and perhaps also its predictive power?).

References

Conrad, Jon M. 1999. Resource Economics. Cambridge, UK: Cambridge University Press.

Dixit, A., and R. Pindyck. 1994. Investment Under Uncertainty. Princeton, NJ: Princeton University Press.